United States
Department of
Agriculture

Forest Service

Pacific Northwest
Research Station

Research Paper
PNW-RP-451
June 1992

Early Survival and Height Growth of Douglas-Fir and Lodgepole Pine Seedlings and Variations in Site Factors Following Treatment of Logging Residues

W. Lopushinsky, D. Zabowski, and T.D. Anderson

Authors

W. LOPUSHINSKY was principal plant physiologist (now retired) when the work was done, D. ZABOWSKI is a research soil scientist, and T.D. ANDERSON is a chemist at the Pacific Northwest Forest and Range Experiment Station, Forestry Sciences Laboratory, 1133 N. Western Ave., Wenatchee, Washington 98801.

Abstract

Lopushinsky, W.; Zabowski, D.; Anderson, T.D. 1992. Early survival and height growth of Douglas-fir and lodgepole pine seedlings and variations in site factors following treatment of logging residues. Res. Pap. PNW-RP-451. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 22 p.

Logging residues were broadcast burned, piled and burned, removed, or left in place after clearcutting in a high-elevation subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.)-lodgepole pine (*Pinus contorta* Dougl. ex Loud.) forest in north-central Washington. Survival, height growth and foliar nutrient content of planted Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) and lodgepole pine seedlings, variations in soil factors (nutrients, temperature, moisture, and compaction), and air temperature were compared for four residue treatments. First- and second-year survival of seedlings planted with a power auger was similar for all residue treatments. During the first growing season, little height growth occurred, and height growth was similar for all residue treatments, probably because of transplant shock. Second-year height growth increased greatly, with the most growth occurring on the burned treatments and the least occurring on the slash-left treatment. Levels of foliar nutrients generally were similar for all residue treatments for both species at the end of the second growing season, but in Douglas-fir, the highest levels of nitrogen (N), sulfur (S), calcium (Ca), and magnesium (Mg) occurred in the pile-burned treatments. Extractable soil nutrients initially increased with both burn treatments, but returned to levels similar to those in other treatments and the surrounding forest soil within 3 years. Twenty-seven percent of Douglas-fir seedlings and 31 percent of lodgepole pine seedlings had terminal shoots or whole tops that had been chewed off during the first year in the slash-left treatment. No damage occurred in the other treatments. Seasonal trends of air and soil temperature were similar for all residue treatments, but during summer, highest afternoon air temperatures occurred in the slash-left treatment. Soil temperature (at 20 cm) in the slash-left treatment during summer remained at 10 °C compared to 14.5 °C in the other treatments. Soil moisture levels remained high throughout the growing season. These results indicate that for the type of high-elevation forest studied, broadcast burning of residues resulted in the best performance of planted seedlings for the first 2 years after residue treatment.

Keywords: Douglas-fir, *Pseudotsuga menziesii*, lodgepole pine, *Pinus contorta*, residue treatment, reforestation, soil nutrients, seedling microclimate.

Summary

Logging slash has generally been burned to reduce fire hazard and clear areas for planting in the coniferous forests on the eastern side of the Cascade Range. Increasing concern about the impacts of slash burning such as smoke pollution and potential losses of nutrients exists, however. This research compared the effects of two types of slash burning: (1) no slash treatment and (2) removal of slash on seedlings and site factors at a high-elevation forest in eastern Washington.

Logging residues were broadcast burned, piled and burned, removed, or left in place after clearcutting in a high-elevation subalpine fir-lodgepole pine forest in north-central Washington. Survival, height growth, and foliar nutrient content of planted Douglas-fir and lodgepole pine seedlings, variations in soil factors such as nutrients, temperature, moisture, and compaction, and air temperature were compared for the four residue treatments.

The survival of first- and second-year seedlings planted with a power auger was similar for all residue treatments. During the first growing season, little height growth occurred, and height growth was similar for all residue treatments, probably because of transplant shock. Second-year height growth increased greatly, with the most growth occurring on the burned treatments and the least occurring on the slash-left treatment. Levels of foliar nutrients were generally similar at the end of the second growing season for all residue treatments and both species, but in Douglas-fir, the highest levels of N, S, Ca, and Mg occurred in the pile-burned treatments. Foliar levels of all elements, except S, were above threshold-deficiency levels. Extractable soil nutrients initially increased with both burn treatments but returned to levels similar to those in other treatments and the surrounding forest soil within 3 years. Twenty-seven percent of Douglas-fir seedlings and 31 percent of lodgepole pine seedlings had terminal shoots or whole tops that had been chewed off during the first year in the slash-left treatment. No damage occurred in the other treatments. Also, first-year damage was less in seedlings planted 2 years after slash treatment. Piling slash with a tractor resulted in a 16-percent increase in bulk density of soil (at 30 cm) on 50 percent of the cleared area. Seasonal trends of air and soil temperature were similar for all residue treatments, but during summer, highest afternoon air temperatures occurred in the slash-left treatment. Soil temperature (at 20 cm) in the slash-left treatment during summer remained at 10 °C compared to 14.5 °C in the other treatments. Soil moisture levels remained high throughout the growing season. These results indicate that for the type of high-elevation forest studied, broadcast burning of residues results in the best performance of planted seedlings for the first 2 years after residue treatment, probably because of an adequate soil temperature for root growth, sufficient nutrient availability, minimal compaction of soil, and animal damage to seedlings.

Introduction

Logging slash created during the harvesting of coniferous forests on the eastern slopes of the Cascade Range of Washington and Oregon has traditionally been burned to reduce fire hazard and to clear the area for planting tree seedlings. Currently, however, there is increasing concern about the impact of slash burning on smoke pollution and loss of site nutrients, which could affect long-term site productivity. Consequently, foresters are considering other options to slash burning such as leaving residues untreated and planting seedlings in existent or created holes in the slash; however, the effects of such treatments on seedling performance are largely unknown. At the same time, timber harvesting is progressing to higher elevations where relatively little is known about the effects of residue treatment on regeneration success. Finally, as more commercial forest land is set aside for endangered species and wilderness areas, pressure will increase to maximize timber production on other lands. Efficient management of these lands will require proper treatment of postharvest residues to assure prompt reforestation.

Burning forest residues after logging can alter the site nutrient balance (Cramer 1974, DeByle 1980, Entry and others 1987, Feller 1988, Hart and others 1981, Little and Klock 1985, Little and Ohman 1988, Rosen and Lundmark-Thelin 1987). Nitrate movement through the soil profile increases significantly when residues are burned (DeByle 1980). Movement of cations also can increase for several years after burning. If nutrients in the ash are not immediately lost through erosion or leaching, they become available for plant growth. Consequently, seedling growth often either increases after slash burning or shows no effect (Ballard and Hawkes 1989, Lotan and Perry 1976, Minore 1986, Vihnanek and Ballard 1988). Flushes in tree growth after burning are attributed to increased rates of nitrification and increased availability of cations. Theoretically, reduction of site nutrients by burning can adversely affect long-term site productivity, but actual impacts on productivity and tree growth over rotation periods typical of Northwest forests are largely unknown (Klock and Grier 1979). Kraemer and Hermann (1979) examined forest plots that had been burned 25 years previously in western Oregon and Washington and found no differences between properties of burned and unburned soils, thereby suggesting that broadcast burning had no lasting effect on chemical and physical properties of soil.

Effects of residue treatment on seedling growth and site nutrients have been studied elsewhere, notably in lodgepole pine (*Pinus contorta* Dougl. ex Loud.) forests in Wyoming (Benson 1982, Schmidt and Lotan 1980), but little information exists about the effects of various residue treatments on seedling performance and site conditions of high-elevation clearcuts in eastern Washington, which differ in soil type, elevation, annual precipitation, and other characteristics from those found in Wyoming. The most relevant work is that by Friend,[1] who found substantial losses of nutrients associated with piling and burning of slash after clearcutting in a high-elevation lodgepole pine and Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) forest in north-central Washington. Burning is not unusual in these high-elevation lodgepole pine-subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) forests; in fact, their

[1] Friend, A.L. 1988. Differences in nutrient distribution between adjacent cut and uncut east-slope Cascade forest stands suggest nutrient losses. Unpublished report. On file with: Forestry Sciences Laboratory, Pacific Northwest Research Station, 1133 N. Western Ave., Wenatchee, WA 98801.

formation is a direct result of periodic wildfires. This paper describes the effects of four residue treatments on the performance of planted conifer seedlings, available soil nutrients, and microclimate after clearcutting in a high-elevation forest in eastern Washington.

Methods

The study area is located on Sugarloaf Ridge (T. 26 N., R. 18 E., NE1/4, sec. 24, Willamette Meridian) on the Entiat Ranger District of the Wenatchee National Forest in north-central Washington. The study site is at an elevation of 1600 m on a broad ridge top with exposure to the northwest at a 10-percent slope. Average annual precipitation is 142 cm per year, and mean annual temperature is 6.0 °C. Summers normally are hot and dry, with only about 13 percent of the precipitation occurring from June to September. Soils are loamy and well drained, with parent materials of weathered gneiss covered by volcanic tephra. The soil is classified as an Andic Xerochrept, Kloochman series. The site was occupied by a mature 80- to 100-year-old stand of subalpine fir, lodgepole pine, and a few scattered old-growth Douglas-fir, and is classified as a subalpine fir/grouse huckleberry plant association.[2]

The stand was clearcut during fall 1983 and summer 1984 creating an opening of approximately 12 ha. Logs were removed as tree-length logs with a rubber-tired skidder. After logging, four residue treatments were applied. Plot sizes ranged from 0.4 to 0.6 ha. Treatments were (1) broadcast burning (BB) with residues burned in place, (2) piling and burning (PB) where residues were piled into windrows by using a D-6 size tractor with a brush blade, (3) cleared (CL) with residues removed to form piles (some fine material such as needles remained), and (4) slash left (SL) where residues were left undisturbed. Residues on the broadcast burn and pile-and-burn plots were burned in fall 1985; additional piles were burned 1 year later in fall 1986.

Amounts and size-class distribution of residues on the broadcast-burn area were measured before and after the burn in fall 1985 with a 1220-m line-intersect inventory (Brown 1974, Sandberg and others 1989). Depth of slash for all treatment areas was up to 1.2 m deep. Fuel consumption for woody residues larger than 7.6 cm in diameter was determined by wrapping wires around 40 logs and measuring preburn and postburn circumferences which were then used to calculate diameter reduction. The preburn load of woody material was 73.2 $Mg \cdot ha^{-1}$ (32.7 tons per acre) of which 80 percent was consumed during burning (table 1). Residue loads on the other treatment areas were similar to those on the broadcast-burn treatment. USDA Forest Service personnel judged the BB burn to be a severe burn with all portions of the BB treatment area combusting at about the same time. Volumes of the piles (residues plus air) and weights of residues were calculated from measured dimensions of the piles, assuming that residue loads before piling were similar to those on the broadcast-burn area. Volumes of piles ranged from 91.7 m^3 (3,240 ft^3) to 599 m^3 (21,200 ft^3), and weights from 1.6 Mg (3,580 lb) to 10.6 Mg (23,400 lb). Combustion of the piles was complete. Duff consumption was determined by measuring the postburn duff reduction around 300 metal and tile pins in the broadcast-burn area.

Because residue-treatment areas were not replicated, treatment differences in this study were not tested for statistical significance. Data shown are treatment averages; where applicable, standard deviations are included to show variation in the data.

---

[2] Williams, C.K.; Smith, B.G. 1991. Forested plant associations of the Wenatchee National Forest. Draft. On file with: Forestry Sciences Laboratory, Pacific Northwest Research Station, 1133 N. Western Ave., Wenatchee, WA 98801.

Table 1—Preburn and postburn residue loads for the broadcast-burn treatment area

Size class	Preburn load	Mass consumed	Mass remaining
Centimeters		*Milligrams per hectare*	
0-0.6	5.6	5.6	0
0.6-2.5	9.2	9.2	0
2.5-7.6	8.5	8.5	0
0-7.6	23.3	23.3 (100)[a]	0 (0)
7.6-15.2	19.9	18.1 (91)	1.8 (9)
15.2-22.9	19.9	13.0 (65)	6.9 (35)
22.9-50.8	10.1	4.5 (44)	5.6 (56)
50.8+	0	0	—
All 7.6+	49.9	35.6 (71)	14.3 (29)
All woody	73.2	58.9 (80)	14.3 (20)
Duff	117.2	77.5 (66)	39.6 (34)
Total	190.4	136.4 (72)	53.9 (28)

[a] Values in parentheses are percentages.

Planted Seedlings

Bare-root, 2-year-old, spring-lifted Douglas-fir and lodgepole pine seedlings obtained from the Wind River Nursery in Washington and the Lava Nursery in Oregon were hand planted in early June 1986 with a tree planting mattock. Planting spots were scalped to remove vegetation, ash or duff to mineral soil. The seed source for both species was the Wenatchee National Forest in eastern Washington from an elevation of from 1200 to 1500 m for the fir and 1680 m for the pine. Before planting, seedlings were graded to obtain stock of uniform top size and root mass. Top sizes and whole seedling fresh weights (average values), respectively, were for Douglas-fir 23.9 cm and 28.0 g, and for lodgepole pine 19.6 cm and 15.1 g. Seedlings were planted at 1-m spacing in six plots on each of the BB, PB, and CL treatment areas with 25 seedlings of both species per plot for a total of 150 seedlings of each species in each of the three treatments. An equal number of fir and pine seedlings were planted in available small openings in the SL treatment; no attempts were made to enlarge openings in the slash. Seedlings on the PB treatment were planted directly on the burned-out piles. Depth of ash was up to 3.5 cm.

Lengths of dormant terminal buds in the lodgepole pine were measured immediately after planting so that net shoot extension (terminal shoot extension minus initial bud length) could be determined. Survival and lengths of terminal shoot growth were determined in the fall. Seedlings were considered live if any green needles were present; a record was kept of the numbers of seedlings damaged by animals.

Because of poor first-year survival of both species in the SL treatment, which we believe was due to difficulty in making deep planting holes with the mattock, seedlings were planted again in each of the four treatmens in mid-May 1987 with a power auger. Bare-root, 2-year-old Douglas-fir and lodgepole pine seedlings obtained from the Wind River Nursery were used. Seed sources and elevations were the same as those for the seedlings planted in 1986. Seedlings were graded for uniformity as described above and were similar in size and weight to those used in 1986. Six plots of each species were planted on each of the four treatment areas for a total of 150 seedlings of each species per treatment. Seedlings were planted in a 1-m spacing on the same treatment areas used in 1986, except that additional windrowed piles, burned in the fall of 1986, were used for the PB treatment in 1987.

Foliar Nutrient Content

Foliage samples were collected in fall 1987 from 19 to 38 seedlings randomly selected from each residue treatment. Current-year growth was cut from the tops of seedlings planted in 1986. Needles were rinsed with deionized water and oven dried at 65 °C. Needles were ground and analyzed for nitrogen content by using a Leco FP-228 Nitrogen Determinator Model 601-700.[3] Sulfur concentration was determined with a Leco high-frequency induction furnace coupled to an automatic titrator (Tiedemann and Anderson 1971). Phosphorus (P) content was measured by using a perchloric acid digestion followed by a colorimetric determination with ammonium-paramolybdate-vandate (Olsen and Sommers 1982). Potassium (K), Ca, and Mg concentrations were determined by perchloric acid digestion with an IL 251 atomic adsorption spectrophotometer.

Soil Nutrients

Randomly chosen soil samples were collected from the Ap and Bw horizons in fall 1986, 1987 and 1988. Samples collected in 1986 (n = 12) were used for total nutrient analyses; samples collected during the 3-year period (n = 4) were used to examine extractable nutrients. Adjacent forest soil from the A and Bw horizons was also collected in 1987 and 1988 to compare forest soil extractable nutrients with soil nutrients after residue treatments.

Bulk soil samples were air dried and ground for nutrient analysis. Total carbon was determined by using a Leco high-frequency induction furnace and Leco carbon analyzer (Nelson and Sommers 1982). A standard kjeldahl digestion with steam distillation was used to measure soil N content (Bremner and Mulvaney 1982). Total S, P, Ca, Mg, and K were determined by using the methods described for measuring foliar nutrients.

Water soluble extractions were taken from air-dried soil by using the saturated-paste method (Rhoades 1982). These extracts were used to examine changes in soil availability of Ca, Mg, and K over time. Extracts were analyzed by using a Jarrel-Ash ICP model 955. Potassium chloride extractions were taken to monitor changes in ammonium and nitrate (Keeney and Nelson 1982). Solution ammonium was analyzed by using steam distillation; nitrate was determined by using a cadmium reduction column (Keeney and Nelson 1982).

---

[3] The use of trade names is for the information and convenience of the reader and does not constitute an endorsement by the U.S. Department of Agriculture of any product to the exclusion of another that may be suitable.

Soil Bulk Density

To evaluate effects of the soil compaction, 12 soil cores were taken at 10- (Ap horizon) and 30-cm (Bw horizon) depths in fall 1986 in the BB, PB, and SL treatments. Cores were ovendried at 105 °C and bulk density was calculated. Tractor tracks (TT) were clearly visible in the cleared area, thereby suggesting that some compaction of soil had occurred when residues were piled into windrows. Therefore, 12 samples were taken in the cleared area from locations where the soil was not visibly disturbed and an additional 12 samples were taken from tractor depressions.

Air and Soil Temperature and Soil Moisture

Air temperature at the seedling crown level (16 cm above the soil surface) was monitored hourly during 1987 at one location in each of the four treatment areas with a shielded thermistor probe and an Omega Inc. datapod.

Soil temperature was measured during 1987 with copper-constantan thermocouples embedded 20 cm deep (Bw horizon) at 10 locations in each of the residue-treatment areas. Soil moisture was measured with a Delmhorst cylindrical gypsum block installed together with each of the thermocouples. Thermocouples and gypsum blocks were installed in fall 1986 and readings were made manually from June through October 1987. Thermocouples were read by using a Wescor Model 65 thermocouple meter; gypsum blocks were read by using a hand-built soil moisture block meter (Fowler and Lopushinsky 1989). Block readings were corrected to a standard temperature of 20 °C (Aitchison and others 1951) and converted to soil matrix potential by using a calibration curve obtained by equilibrating blocks in a ceramic plate extractor.

Results and Discussion

Seedling Survival and Growth

First-year survival of Douglas-fir seedlings planted in 1986 ranged from 75 to 84 percent for the BB, PB, and CL treatments and was 67 percent for the SL residue treatment (fig. 1). Survival the next year (year 2) declined slightly in the BB, PB, and CL treatments, with values ranging from 65 to 79 percent, while survival in the SL treatment dropped to 29 percent. First-year survival of lodgepole pine planted in 1986 ranged from 68 to 75 percent for the BB, PB, and CL treatments; survival in the SL treatment was 50 percent. Second-year survival of lodgepole pine for the BB, PB, and CL declined slightly; survival ranged from 63 to 71 percent. Survival for the SL treatment was 32 percent.

First-year survival of Douglas-fir seedlings planted in 1987 was high, ranging from 90 to 98 percent for all treatments. Second-year survival decreased slightly for all treatments. The lowest survival (81 to 90 percent) occurred in the SL treatment both years. First-year survival of lodgepole pine planted in 1987 also was high (99 to 100 percent for the BB, PB, and CL treatments and 95 percent for the SL treatments). Second-year survival of lodgepole pine remained high (94 to 99 percent) and essentially unchanged for all treatments.

The results show that the only effect of residue treatment on the survival of seedlings planted in 1986 was reduced survival in the SL treatment, especially during the second growing season, but this probably was a problem associated with the difficulty of making proper planting holes with tree planting mattocks. When seedlings were planted again in 1987 with an auger, survival in the SL treatment was only slightly less then it was in the other treatments.

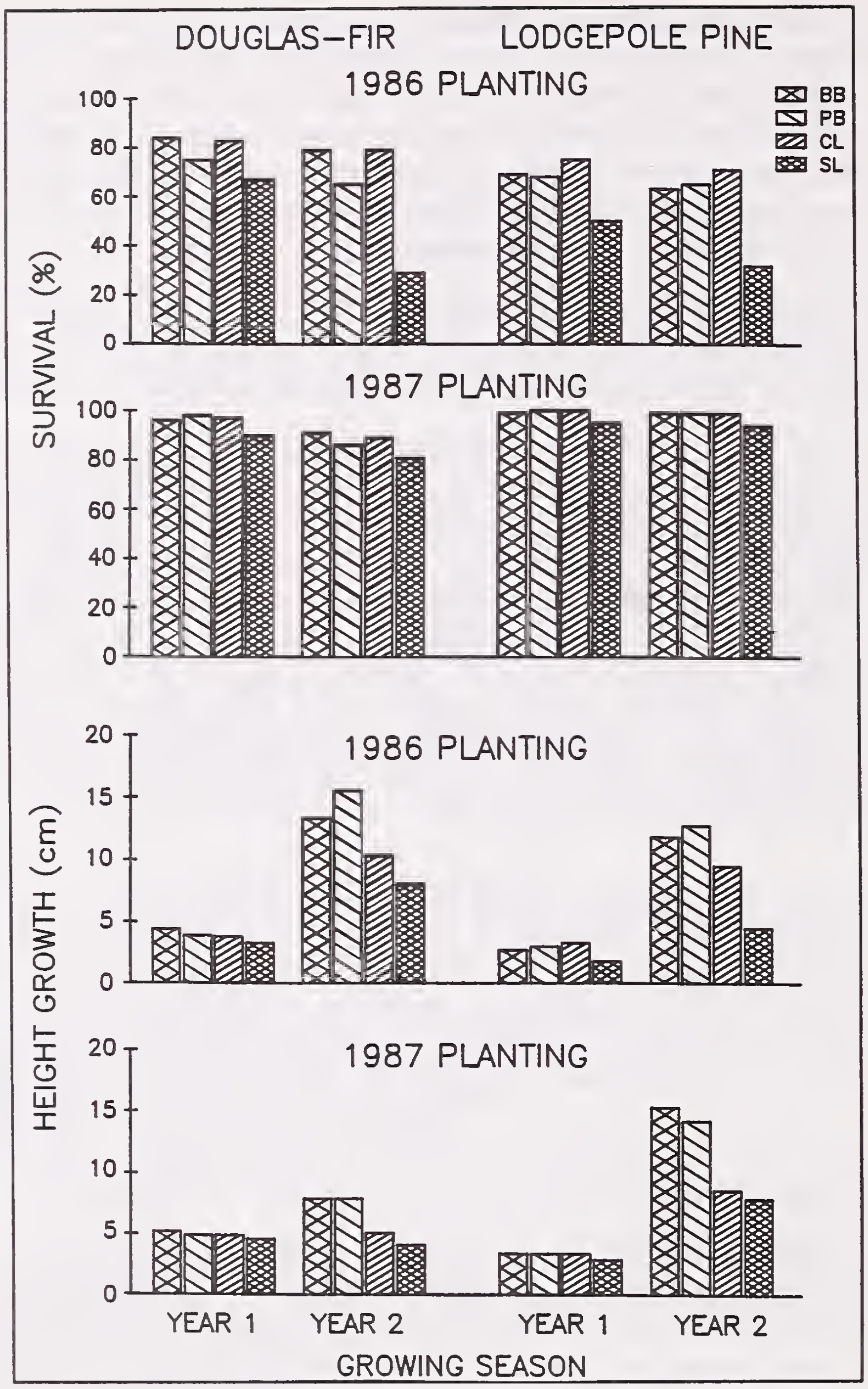

Figure 1—First- and second-year survival and height growth of Douglas-fir and lodgepole pine seedlings planted in spring 1986 and 1987 after four residue treatments in 1985 and 1986. Treatments were (1) broadcast burned (BB), (2) piled and burned (PB), (3) cleared (CL), and (4) slash left (SL). In 1986, seedlings were planted with a tree planting mattock, and in 1987, with a power auger.

The lack of any effect of burning on survival found in this study is consistent with the results of other studies. Shearer (1980), in a residue treatment study in northwestern Montana, found similar survival rates for Douglas-fir and Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) seedlings on burned and unburned clearcuts 2 years after planting. Also, Schmidt and Lotan (1980), in a residue treatment study in Wyoming, found that five growing seasons after planting, nearly 90 percent of planted lodgepole pine seedlings survived on plots where residue was piled and burned compared to only 50 to 60 percent on plots where residues were either removed or chipped and spread.

Height growth of Douglas-fir seedlings planted in 1986 ranged from 3.3 to 4.4 cm for the four treatments (fig. 1). Height growth the second year increased greatly, with the most height growth (13.3-15.5 cm) occurring in the BB and PB treatments and the least growth (8.0 cm) occurring in the SL treatment. First-year height growth of lodgepole pine seedlings planted in 1986 ranged from 1.8 to 3.3 cm for the four treatments. Height growth of lodgepole pine the second year increased greatly, with the most height growth (11.8-12.7 cm) occurring in the BB and PB treatments; height growth for the SL treatment was only 4.5 cm.

First-year height growth of Douglas-fir seedlings planted in 1987 was similar for all treatments, ranging from 4.6 to 5.2 cm. Height growth the second year increased to about 8.0 cm for the BB and PB treatments and 5.1 cm for the CL treatment. Height growth the second year in the SL treatment was only 4.1 cm, which was lower than the first year. First-year height growth of lodgepole pine seedlings planted in 1987 was the same (3.4 cm) for all treatments except the SL treatment (2.9 cm). Second-year height growth of lodgepole pine increased, particularly for the BB and PB treatments (15.3 and 14.2 cm, respectively), but growth increases for the CL and SL treatments were smaller (8.6 and 7.9 cm, respectively).

The small amount of first-year height growth found for all of the residue treatments is typical of limited shoot growth frequently observed in newly planted conifer seedlings, probably as a result of transplant shock. Also typical is a large increase in height growth in subsequent years, as was found in this study. Second-year height growth of Douglas-fir planted in 1987 did not increase as much as it did in seedlings planted in 1986. This particular lot of Douglas-fir seedlings probably was somewhat low in vigor because minimal height growth also was observed on other clearcuts where the same lot of seedlings was used. If seedling vigor was responsible for the small increase in growth, it did not adversely affect survival. Height growth is probably a more sensitive indicator of poor vigor than survival as seedlings were considered live for survival counts if any green needles were present. Second-year height growth for both Douglas-fir and lodgepole pine planted in 1986 and 1987 was consistently greatest for the BB and PB treatments, intermediate in the CL treatment, and least in the SL treatment. The poor second-year height growth in the SL treatment was probably due to the low soil temperature associated with that treatment. Studies have shown that low soil temperature reduces height growth, stomatal conductance, and shoot water potential in Douglas-fir seedlings (Lopushinsky and Kaufmann 1984).

Increased height growth of conifer seedlings planted after residues were burned has been observed for several species, including Douglas-fir (Vihnanek and Ballard 1988), lodgepole pine (Lotan and Perry 1976; Schmidt 1982), white spruce (*Picea glauca* (Moench) Voss) (Ballard and Hawkes 1989), and radiata pine (*Pinus radiata* D. Don) (Ferguson and McKimm 1975). Minore's (1986) study of seedling performance on plantations in southwestern Oregon where residues were broadcast burned and piled-and-burned found that heights of 5-year-old Douglas-fir seedlings were not affected by broadcast burning; however, heights were lower than expected where residues were piled and burned.

Animal Damage

Considerable animal damage to seedlings occurred during the first year. Twenty-seven percent of Douglas-fir seedlings planted in 1986 had terminal shoots or whole tops chewed off in the SL treatment, presumably by rodents. No damage occurred in the BB, PB, or CL treatments. Thirty-one percent of the lodgepole pine seedlings planted in 1986 exhibited animal damage in the SL treatment compared to only 1 percent in the CL treatment and none in the BB and PB treatments. First-year animal damage was less for seedlings planted in 1987. For Douglas-fir, 18, 6, 3, and 0 percent, respectively, of seedlings in the SL, CL, PB, and BB treatments were damaged. Six percent of the lodgepole pine seedlings in the SL treatments were damaged. No damage occurred in the other treatments.

Studies of responses of small-mammal populations to logging consistently show that small mammals increase dramatically during the first few years after clearcutting, with species composition related to habitats resulting from harvesting methods (DeByle 1981, Maquire 1983, Ream and Gruell 1980, Tevis 1956). Ream and Gruell (1980) point out that many species of small mammals continue to inhabit areas where residues are removed mechanically, as in the CL treatment of the present study. Where residues were left in place (SL treatment), the numbers of most small mammals already present could be expected to increase. The lack of damage to seedlings in the BB treatment in the present study probably is the result of some mortality of small mammals during the broadcast burn and the likely reluctance of small mammals to enter the burned area because of an increased risk of predators. The fact that a decrease in first-year animal damage in the SL area in 1987, 2 years after residue treatment, was accompanied by some damage in the CL and BB treatments, where previously none had occurred, suggests a redistribution of small mammals with time. It was also observed that the depth of the slash decreased after compression by snowpacks during winter. Findings from the present study suggest that if residues are left untreated, damage to planted Douglas-fir and lodgepole pine seedlings can occur during the first 2 years, compared to little or no damage in broadcast burned areas.

Foliar Nutrients

Levels of foliar nutrients of both Douglas-fir and lodgepole pine were generally similar for all residue treatments, except that some elements were consistently higher in the PB treatment (fig. 2). In Douglas-fir, the highest level of N, S, Ca, and Mg occurred in the PB treatment. This trend was not observed in lodgepole pine. Also, levels of foliar nutrients were generally slightly less in lodgepole pine than in Douglas-fir. For both species, sample variation was within one standard deviation. Levels of all nutrients in foliage, except S, were above threshold deficiency levels with no indication that any

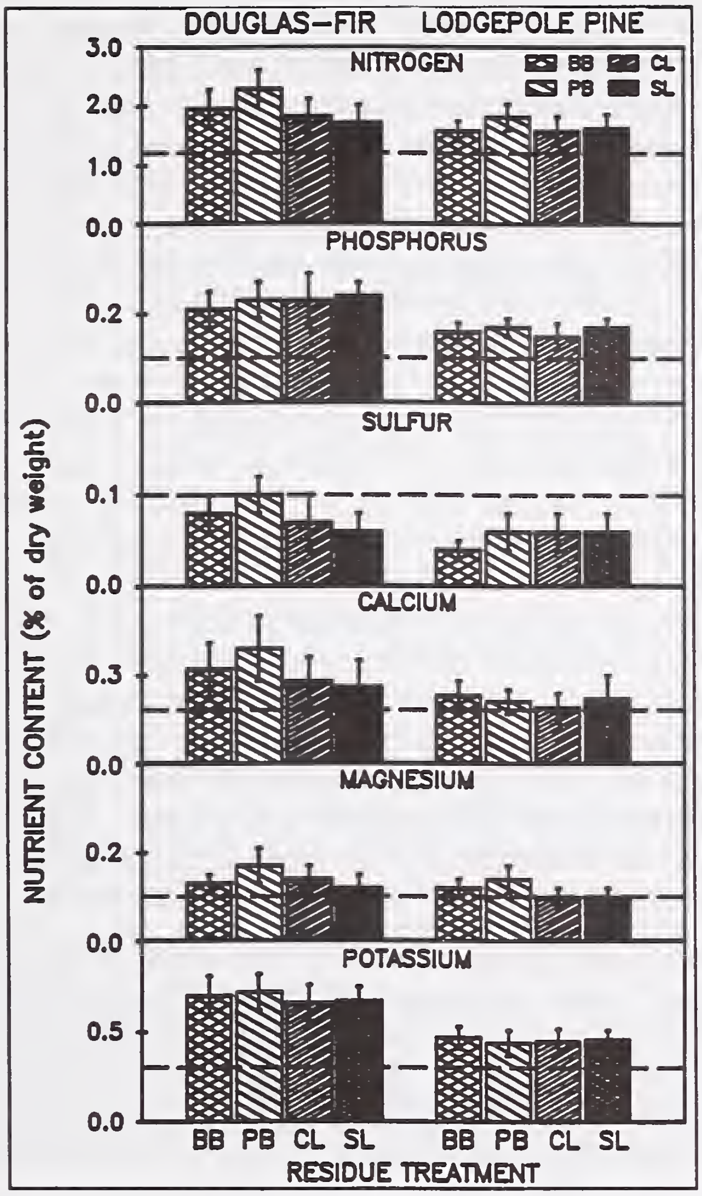

Figure 2—Amounts of nutrients in current year foliage of Douglas-fir and lodgepole pine seedlings after four residue treatments in 1985. Treatments were (1) broadcast burned (BB), (2) piled and burned (PB), (3) cleared (CL), and (4) slash left (SL). Foliage samples were collected in fall 1987 from seedlings planted in 1986. Horizontal lines through the bar graphs represent deficiency threshold levels for each element. Deficiency levels are from Youngberg (1984) and Pritchett and Fisher (1987). Vertical bars indicate one standard deviation.

treatment caused any deficiency in foliar nutrients. A sulfur concentration of 0.1 percent is considered adequate in foliage of conifer seedlings (Landis 1985). By this criterion, both Douglas-fir and lodgepole pine seedlings in our study seem to be deficient for all residue treatments, but the low levels do not seem to be unusual for forest trees. Clayton and Kennedy (1980) report a S concentration of 0.09 percent for current-year needles of Douglas-fir in Idaho, and Cochran and others (1986) report S concentrations of 0.07 to 0.09 percent in the foliage of vigorous Douglas-fir trees in a plantation in eastern Washington.

Although considerable amounts of N and S in residues and duff can be lost through volatilization during combustion (DeBell and Ralston 1970, Kimmins and Feller 1976), there were no reductions in the present study in amount of foliar N or S for burned compared to unburned treatments. This may be due in part to the fact that foliar nutrients in the present study were measured after only two growing seasons when there still may have been some residual effects of fertilization during nursery culture of the seedlings. Other studies, however, also have found little effect of slash burning on foliar N content of planted conifer seedlings. DeByle (1980) found that foliar nutrient concentrations in lodgepole pine after five growing seasons did not differ for broadcast-burned, pile-burned and slash chipped-removed residue treatments, and there were no indications of nutrient deficiencies. Ballard and Hawkes (1989), studying residue treatment effects in British Columbia, report that foliar concentrations of P, K, and S in planted white spruce were significantly higher within piled and burned windrows than between windrows, although the concentration of foliar N was not significantly lower between the windrows. In the same study, the foliage of planted lodgepole pine seedlings had significantly higher concentrations of P, K, and S within windrows than between them; but within windrows, lodgepole pine foliage also had higher levels of N and Ca. Ballard and Hawkes (1989) suggest that accumulation of N and S during windrowing, together with their release in available forms in the ash, might compensate somewhat for the loss of these elements through volatilization. Thus, the results of the present study and other work indicates that, for at least several years after seedlings are planted, burning residues after clearcutting does not necessarily adversely affect seedling nutrient levels.

Soil Nutrients

Little difference was found in soil N among treatments, with values ranging from 0.10 to 0.12 percent in the A horizon and from 0.07 to 0.08 percent in the Bw horizon. Soil carbon also showed little difference among treatments, with values ranging from 2.9 to 3.2 percent in the A, and from 1.6 to 1.9 percent in the Bw. Soil P values averaged 0.11 percent for all treatments. Total soil Ca, K, Mg, and S were lower than for most soils, with values averaging 0.23, 0.12, 0.19, and 0.03 percent, respectively.

Extractable ammonium, nitrate, Ca, and K are shown in figure 3 along with soil pH for each treatment and the soil from the surrounding uncut forest for 1986 through 1988. Both burn treatments initially increased ammonium, Ca and K, but not nitrate. Nitrate increases did occur in year 2 with the PB treatment. This lag suggests that nitrification did not not begin until year 2. The CL and SL treatments seemed to have little effect on extractable nutrients. By 1988, extractable nutrients from the burned treatments had returned to levels similar to those in the uncut forest stand with the exception of Ca in the PB treatment. In the A horizon, pH was decreased by both the BB and SL treatments, whereas the PB treatment elevated the pH of the Bw horizon. The CL treatment had little effect on pH.

Because no deficiencies were observed in the seedling foliage, it is unlikely that the changes observed in extractable soil nutrients will reduce seedling growth during the first few years after residue treatment. The initial increases in extractable nutrients found with burning suggest that some nutrients may be lost from the site during this period through leaching. Some studies (Flinn 1978, Flinn and others 1979, Keeves 1966) have shown that burning or clearing of residues creates nutrient losses later that extend well through the rotation period; however, other studies have found no effect on long-term nutrient availability from burning (Kraemer and Hermann 1979, Squire and others 1985). Declines in nutrient availability could also occur at this site later in the rotation, but no reduction was detected in the first 3 years after treatment.

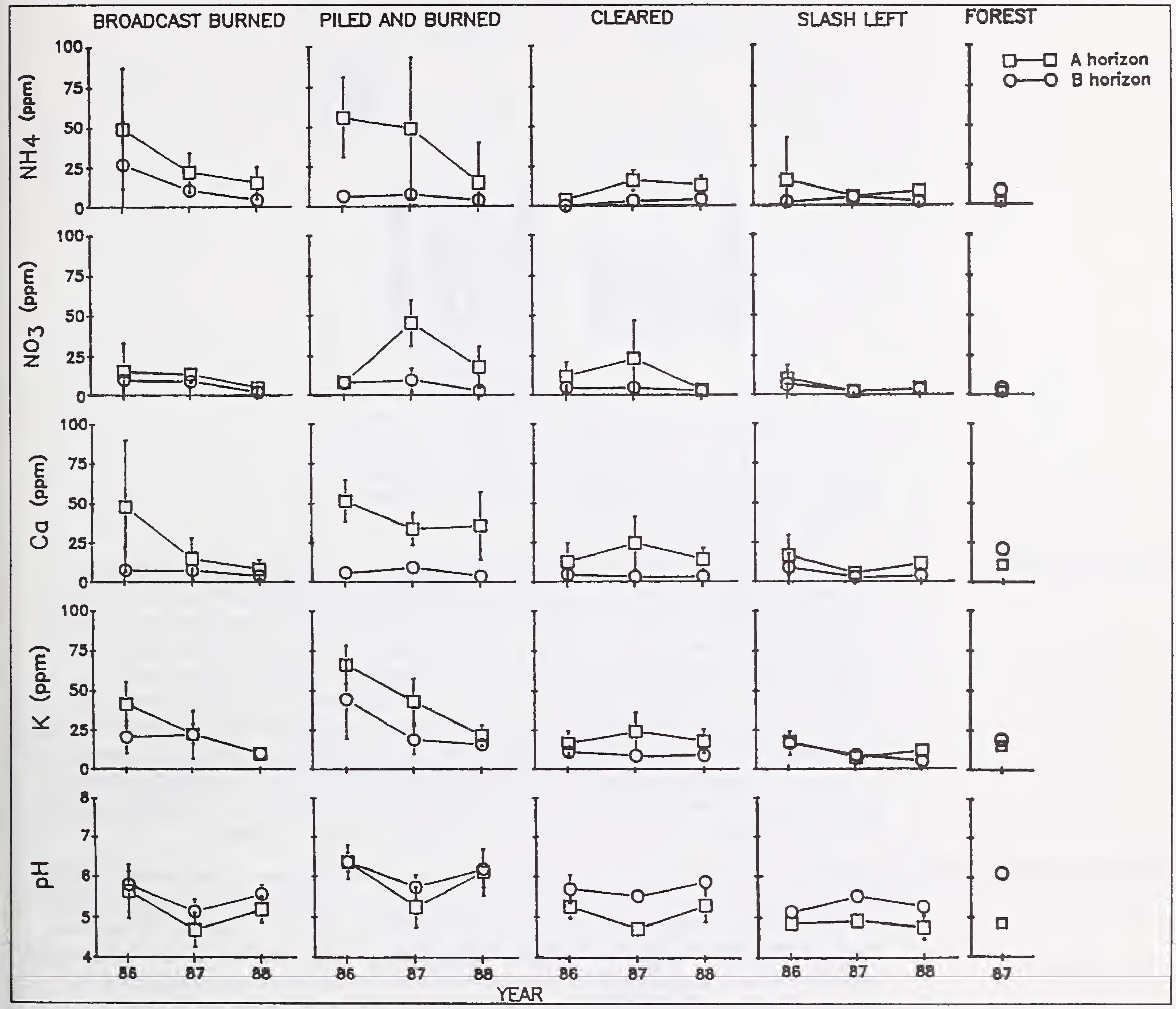

Figure 3—Extractable soil nutrients from the A and B horizon from the four residue treatments for 1986, 1987, and 1988. Extractable soil nutrients from the uncut surrounding forest are also included for comparison.

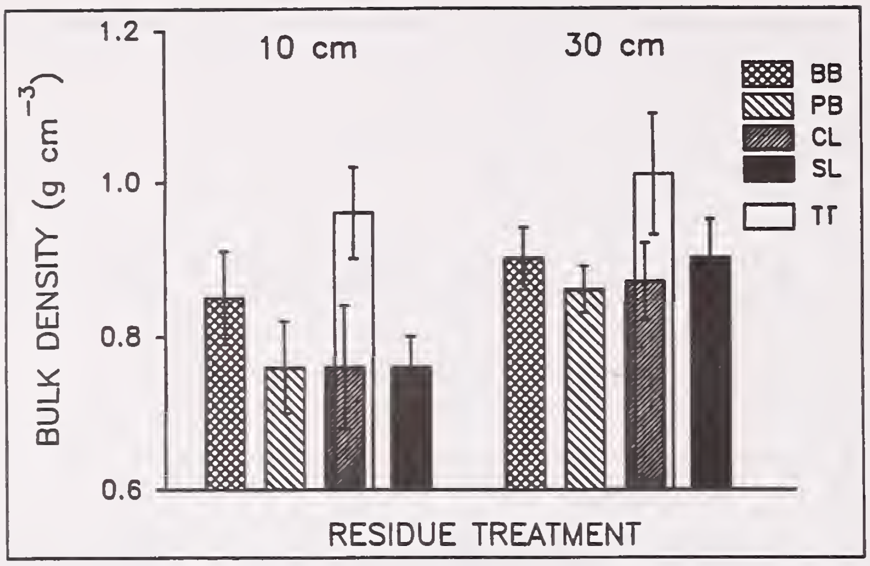

Figure 4—Soil bulk density at soil depths of 10 and 30 cm in fall 1986 after four residue treatments in 1985. Treatments were (1) broadcast burned (BB), (2) piled and burned (PB), (3) cleared (CL), and (4) slash left (SL). Bulk density in tractor tracks (TT) from the cleared area is shown for comparison with nontracked portions (CL). Vertical bars indicate one standard deviation.

Soil Bulk Density

Soil bulk density at a depth of 10 cm ranged from 0.76 to 0.85 g cm^{-3} for the four treatments (fig. 4). Bulk density in tractor tracks (tractor tracks covered about 50 percent of the cleared area) at a depth of 10 cm was 0.96 g cm^{-3} compared to 0.76 g cm^{-3} for nontracked portions of the cleared area, an increase of 26 percent in bulk density. Bulk densities at a depth of 30 cm ranged from 0.86 to 0.90 g cm^{-3}. In tractor tracks, bulk density was 1.01 g cm-3, an increase of 16 percent over nontracked ground. Similar results have been reported by Clayton (1990) who found that soil density on main skid trails yarded by tractor exceeded the natural bulk density by 15 percent. Seedlings were not planted in tractor tracks, therefore specific effects of compaction on growth were not determined. However, the initially low bulk density of this soil probably will prevent any adverse effects from compaction.

Air and Soil Temperature

Maximum and minimum air temperatures at the seedling crown level varied greatly during the summer and fall of 1987 (fig. 5). Maximum air temperatures were similar for all residue treatments except for the SL treatment, where maximum air temperature was sightly higher from June to early August than it was in the other treatments. Between June 1 and August 31, the maximum air temperature recorded, 34.5 $^{\circ}$C, occurred twice in the SL treatment (June 30 and August 8) and once in the CL treatment. Not all of these temperatures are discernible in figure 5 as it shows data plotted for every fifth day.

Minimum air temperatures also were similar for all residue treatments. From June 1 to August 31, the lowest temperature recorded, -3.0 $^{\circ}$C, occurred on August 21 in the BB treatment. Air temperature of 0 $^{\circ}$C or lower occurred on 6, 7, 8, and 9 days, respectively, in the PB, CL, SL, and BB treatments. The lack of difference in air temperature for the four residue treatments is in agreement with results of a residue-treatment study in a high-elevation lodgepole pine stand in Wyoming (Hungerford 1980), where air temperatures were similar above cleared, broadcast-burned, and chip-spread treatments.

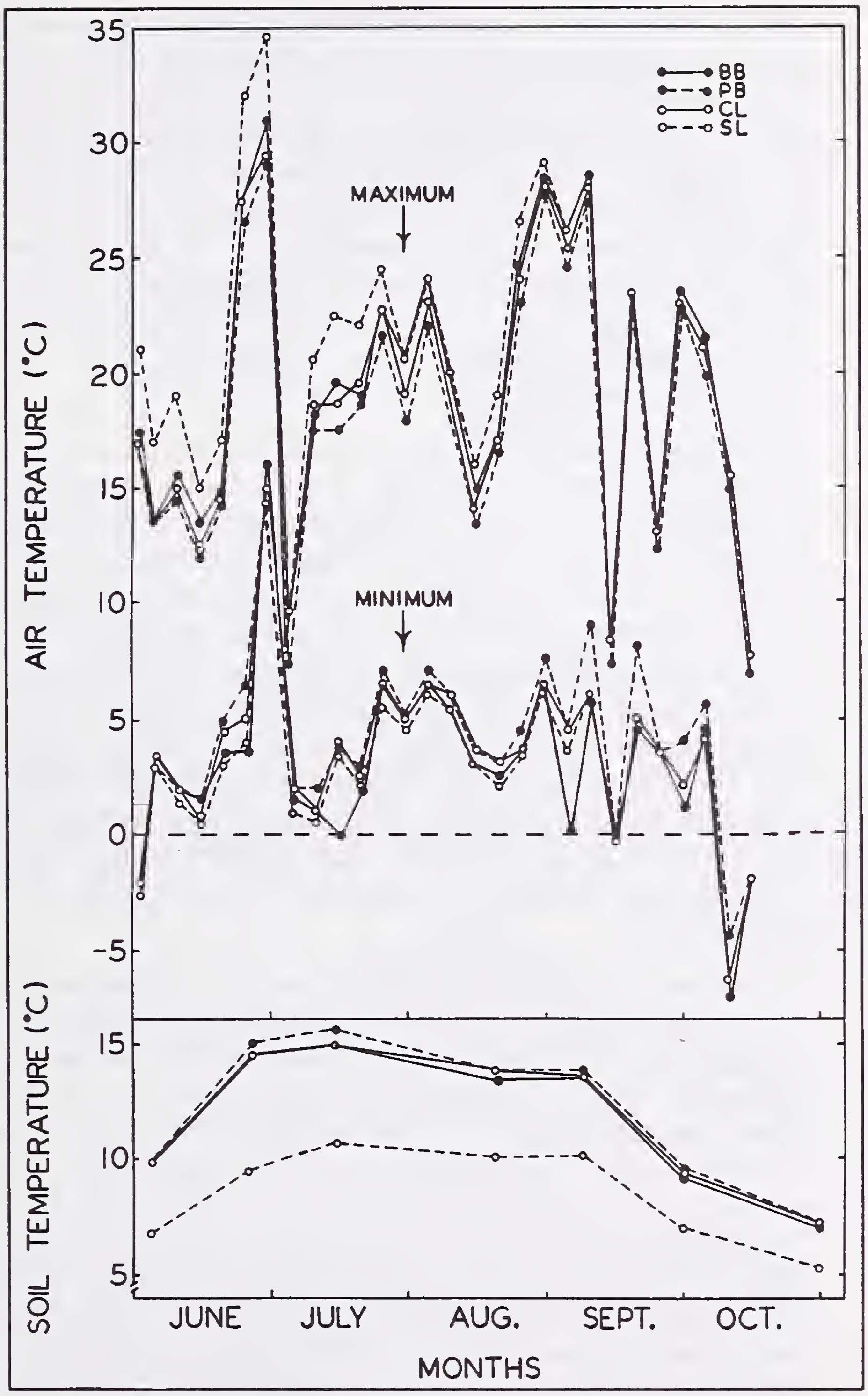

Figure 5—Seasonal variation in maximum and minimum air temperatures during 1987 at the seedling crown level (22 cm above soil surface), and soil temperature (20 cm below soil surface) after four residue treatments. Treatments were (1) broadcast burned (BB), (2) piled and burned (PB), (3) cleared (CL), and (4) slash left (SL). Air temperatures are maximums and minimums during a 24-hour period at 5-day intervals.

The seasonal trend of soil temperature was similar for all treatments. Soil temperature increased during June, remained relatively high in July and into early September, and then declined. Soil temperatures were similar for the BB, PB, and CL treatments, but soil temperatures in the SL treatment ranged from 2.0 to 5.1 °C lower, presumably because of shading of the soil surface by the residues. From mid-June to early September, average soil temperature at the seedling root depth (20 cm) for the SL treatment was 10 °C compared to 14.5 °C for the other three treatments. Lower soil temperature in the SL treatment could adversely affect root growth. Lopushinsky and Max (1990) found that root growth in high-elevation sources of lodgepole pine and Douglas-fir seedlings at a soil temperature of 10 °C was only 10 percent and 17 percent, respectively of root growth at 14.5 °C.

Some studies have found high soil surface temperatures that are potentially lethal in clearcuts. Hungerford and Babbit (1987) found that surface temperatures in clearcuts in Douglas-fir-subalpine forests in Montana and Wyoming frequently exceeded 56 °C and were related to seedling survival levels. The temperatures of burned and littered surfaces was similar, with that of chip-covered surfaces being significantly cooler. Fowler and Helvey (1981) also found little difference in soil surface temperatures of burned and unburned plots in a clearcut in northeastern Oregon, but the surface soil temperature of a chip-covered surface was cooler. Soil surface temperatures were not measured on the four treatment areas in the present study; however, the relatively high seedling survival rates for the burn treatments (BB and PB) suggest that surface temperatures in the present study were not excessively high. Blackened soil surfaces in the burned areas that might cause excessive heating of conifer stems were largely disrupted and mixed with mineral soil during planting of the seedlings by hand and with an auger.

Diurnal trends of air temperature were similar for all residue treatments, except that during clear days from June to mid-August, air temperature in the SL treatment was as much as 5.0 °C higher during the afternoon than air temperature in the other treatments (fig. 6). This difference decreased during summer, and by September 14, there was no difference. For all treatments, the onset of increase in air temperature occurred later in the day as the growing season progressed, and daily maximum temperature occurred earlier in the day. The occurrence of higher air temperature in the SL area was unexpected because shading by residues would be expected to produce lower air temperatures than those found on exposed plots. Other studies have shown that shading lowers soil temperature and increases survival of Douglas-fir and lodgepole pine seedlings, particularly on hot, dry reforestation sites (Baer and others 1977, Childs and Flint 1987, Coffman 1975). The most likely explanation for the increased air temperature in the SL treatment in the present study is that heat absorbed by the slash from direct solar radiation warms the air by convective heating. A contributing factor is that air exchange in the slash is restricted because of a reduction in turbulence and vertical exchange. Air temperature at the seedling level probably will change somewhat as slash heights decrease as a result of settling and compression by snow loads, but soil temperatues are not likely to be affected much because of the insulating effect of the slash and duff layer.

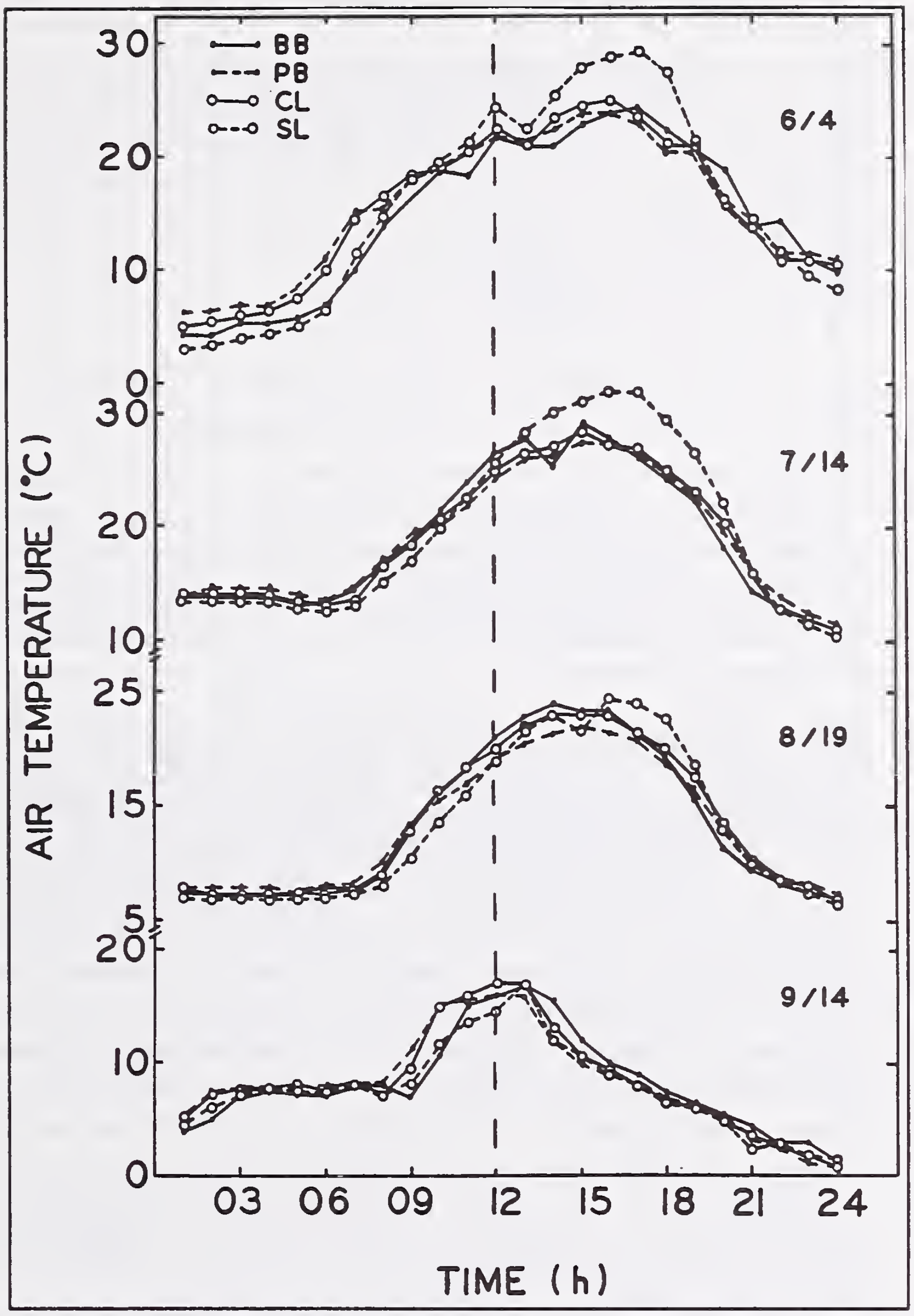

Figure 6—Seasonal variations in diurnal trends of air temperature during 1987 at the seedling crown level (22 cm above soil surface) during clear days in summer and fall after four residue treatments in 1985. Treatments were (1) broadcast burned (BB), (2) piled and burned (PB), (3) cleared (CL), and (4) slash left (SL).

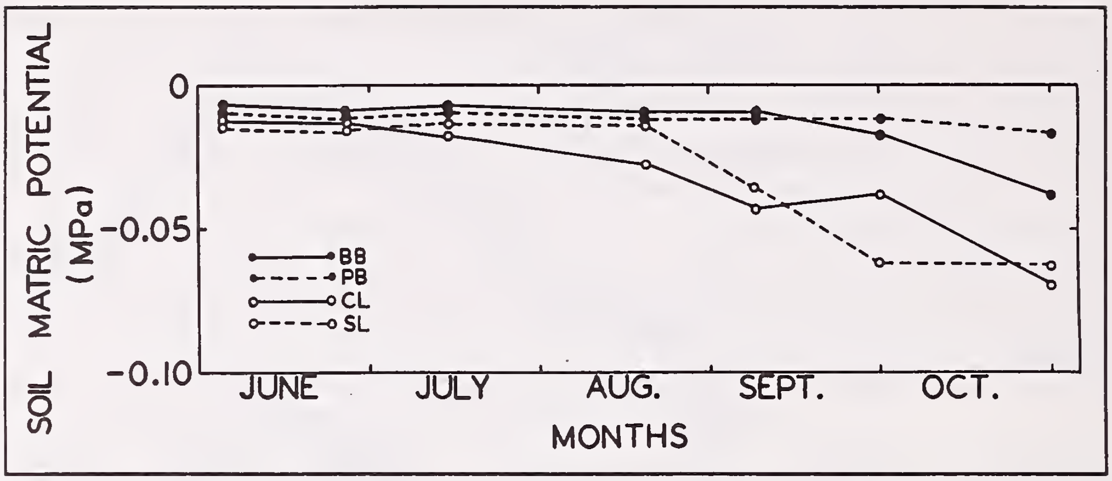

Figure 7—Seasonal trend of soil matric potential during 1987 at a depth of 20 cm after four residue treatments in 1985. Treatments were (1) broadcast burned (BB), (2) piled and burned (PB), (3) cleared (CL), and (4) slash left (SL). Gypsum block locations in the BB and PB treatments remained free of vegetation, but soil moisture in the CL and SL treatment areas were influenced by various amounts of residual and newly developing vegetation near block locations.

Soil Moisture

Soil matric potentials for all treatments remained high, near -0.01 MPa, until mid-July of 1987 (fig. 7). By mid-August, matric potential in the CL treatment declined slightly, but remained unchanged in the BB, BP, and SL treatments. Matric potentials for the CL and SL treatments declined during September and October. By the end of October, values ranged from -0.06 to -0.07 MPa (-0.6 to -0.7 bar). Differences in late-summer trends of matric potential for the BB and PB treatments, compared to the CL and SL treatments probably reflect differences in amounts of vegetation present on those areas. The BB and PB areas were largely devoid of vegetation after the burn treatments. In addition, areas where piles had been burned were covered with a thick layer of ash that would tend to minimize loss of water by evaporation from the soil surface. In contrast, the CL and SL areas contained various amounts of residual vegetation. In any case, the lowest matric potential measured during the growing season, -0.04 MPa, recorded in early September, is a negligible soil moisture stress. Thus, it is not likely that the growth of seedlings on any of the four treatment areas was limited by moisture stress during 1987. In a few isolated instances, vegetation sprouting immediately adjacent to gypsum blocks resulted in matric potentials of -0.37 to -0.40 MPa by October. Again, this moisture stress is not excessive and occurred too late in the season to seriously impact seedling survival or growth.

The high seasonal soil moisture levels found on this clearcut are not surprising, particularly at this high elevation. Other studies have consistently shown that clearcut areas retain higher levels of soil moisture than do uncut forests. Herring (1968) found that clearcutting of lodgepole pine in north-central Washington results in an increase of 10.7 cm in soil moisture in a 183-cm soil profile. Herring (1970) also reports that clearcutting ponderosa pine in central Washington resulted in an increase of 2.6 cm of water per 30 cm of soil. Bethlahmy (1962) found that clearcutting mature Douglas-fir forests in western Oregon results in reduced depletion and accelerated recharge of soil moisture. The largest increase in soil water content documented for an interior coniferous forest was a 20-cm increase shown by Klock and Lopushinsky (1980) for a clearcut grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.)/Engelmann spruce forest in northeast Oregon.

Because of patchy regrowth of vegetation after logging, there is no "average" soil water potential characteristic of, for example, the BB area. Instead, that area consists of extensive portions devoid of vegetation that remain uniformly high in soil moisture throughout the growing season, along with scattered spots of developing vegetation, which create small local areas of reduced soil moisture. Because these spots initially occupy a small percentage of the overall area, soil moisture conditions associated with them have no significant effect on the majority of the planted seedlings. With time, however, soil moisture stress can be expected to increase on all treatment areas as trees and other vegetation reoccupy the site.

Conclusions

Type of residue treatment had no effect on first- or second-year survival of Douglas-fir and lodgepole pine seedlings when seedlings were planted with a power auger. Use of a power auger is recommended when planting seedlings in untreated slash because of the difficulty of making suitable planting holes with a tree planting mattock. That first-year height growth was minimal for all residue treatments and that type of residue treatment had no effect on first-year height growth for both Douglas-fir and lodgepole pine suggest that expression of first-year height growth responses was limited by transplant shock after outplanting. Apparently transplant shock was not a limiting factor the second growing season because height growth increased greatly and variable height growth responses to residue treatment were observed. Greatest height growth occurred on the burned treatments and the least occurred on the slash-left treatment. Seedlings planted in untreated slash can be expected to exhibit some animal damage during the first two growing seasons, compared to little or no damage in the other treatments.

Type of residue treatment had no effect on levels of foliar nutrients at the end of the second growing season. Except for sulfur, all macronutrients were above deficiency levels. Soil nutrients showed an initial increase in extractable nutrients with the burn treatments, but had mostly returned to ambient levels within 3 years after residue treatment. Soil bulk density was not substantially affected by any treatment.

Type of residue treatment had no effect on the seasonal trend or magnitude of maximum and minimum air temperature at the seedling level, but during summer, highest air temperatures in the afternoon occurred in the slash-left treatment. Type of residue treatment also had no effect on the seasonal trend or magnitude of soil temperatures for the broadcast burned, piled-burned, and cleared treatments, but soil temperature was lower in the slash-left treament. Soil temperature at the root zone in the slash-left treatment was low enough during summer (10 ^{o}C) to limit seedling root growth. This suggests that planting spots in untreated slash should be made fairly large to minimize shading effects and scalped to mineral soil to remove the insulating effect of the surface duff layer. Throughout the growing season, soil moisture remained above levels known to limit growth, thus soil moisture availability was not a limiting factor.

Increased height growth after burning, and the lack of adverse effects on seedling foliage nutrient contents, suggest that for this type of high-elevation site and forest, broadcast burning of residues results in the best seedling performance for at least 2 years after residue treatment. This treatment maintains soil temperatures adequate for seedling root growth, provides sufficient soil nutrients for growth, and results in minimal compaction of soil and animal damage to seedlings. Results of the present study apply directly only to the specific site studied, but they may also apply in general to other high-elevation subalpine fir-lodgepole pine forests on similar slopes, aspects, and soils in eastern Washington. Sites on other soils, on steep slopes and other aspects may exhibit different seedling, soil, and microclimatic responses to residue treatments. Also, the results of the present study represent seedling, soil and, microclimatic responses for only the first several years after clearcutting; long-term effects of residue treatments on these sites are unknown.

Acknowledgments

We thank Dick Schellhaas and the Entiat District of the Wenatchee National Forest for their assistance in providing the study site and arranging residue treatments. We also thank Pat Cochran, Sue Little, and Andrew Youngblood for reviewing this manuscript.

English Equivalents

When you know:	Multiply by:	To find:
Centimeters (cm)	0.394	Inches
Meters (m)	3.281	Feet
Grams (g)	0.0022	Pounds/cubic foot
Grams/cubic centimeter (g/cm^3)	62.4	Pounds/foot
Megagrams/hectare (Mg/ha)	0.446	Tons/acre
Cubic meters (m^3)	35.3	Cubic feet
MegaPascals (MPa)	10	Bars
Degrees Celsius (°C)	1.8 and add 32	Degrees Farenheit
Hectares (ha)	2.471	Acres

Literature Cited

Aitchison, G.D.; Butler, P.F.; Gurr, C.G. 1951. Techniques associated with the use of gypsum block soil moisture meters. Australian Journal of Applied Science. 2: 56-72.

Baer, M.; Ronco, F.; Barney, C.W. 1977. Effects of watering, shading and size of stock on survival of planted lodgepole pine. Res. Note RM-347. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 4 p.

Ballard, T.M.; Hawkes, B.C. 1989. Effects of burning and mechanical site preparation on growth and nutrition of planted white spruce. Forestry Canada Information Rep. BC-X-309. Victoria, BC: Pacific Forestry Center. 19 p.

Benson, R.E. 1982. Management consequences of alternative harvesting and residue treatment practices—lodgepole pine. Gen. Tech. Rep. INT-132. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station.

Bethlahmy, N. 1962. First year effects of timber removal on soil moisture. Bulletin International Association of Science Hydrology. 7: 34-38.

Bremner, J.M.; Mulvaney, C.S. 1982. Nitrogen-total. In: Page, A.L.; Miller, R.H.; Keeney, D.R., eds. Methods of soil analysis, part 2. Madison, WI: American Society of Agronomy: 595-624.

Brown, J.K. 1974. Handbook for inventorying downed woody material. Gen. Tech. Rep. INT-16. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 24 p.

Childs, S.W.; Flint, L.E. 1987. Effect of shadecards, shelterwoods and clearcuts on temperature and moisture environments. Forest Ecology and Management. 18: 205-217.

Clayton, J.L. 1990. Soil disturbance resulting from skidding logs on granitic soils in central Idaho. Res. Pap. INT-436. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 8 p.

Clayton, J.L.; Kennedy, D.A. 1980. A comparison of the nutrient content of Rocky Mountain Douglas-fir and ponderosa pine trees. Res. Note INT-281. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 13 p.

Cochran, P.H.; Lopushinsky, W.; McColley, P.D. 1986. Effect of operational fertilization on foliar nutrient content and growth of young Douglas-fir and Pacific silver fir. Res. Note PNW-445. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 10 p.

Coffman, M. 1975. Shade from brush increases survival of planted Douglas-fir. Journal of Forestry. 11: 726-728.

Cramer, O.P. 1974. Environmental effects of forest residues management in the Pacific Northwest. Gen. Tech. Rep. PNW-24. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 410 p.

DeBell, D.S.; Ralston, C.W. 1970. Release of nitrogen by burning light forest fuels. Soil Science Society of America, Proceedings. 34: 936-938.

DeByle, N.V. 1980. Harvesting and site treatment influences on the nutrient status of lodgepole pine forests in western Wyoming. In: Environmental consequences of timber harvesting in Rocky Mountain coniferous forests: Proceedings of a symposium; 1979; Missoula, MT. Gen. Tech. Rep. INT-90. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 137-155.

DeByle, N.V. 1981. Clearcutting and fire in the larch/Douglas-fir forests of western Montana-a multifaceted research summary. Gen. Tech. Rep. INT-99. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 73 p.

Entry, J.A.; Stark, N.M.; Loewenstein, H. 1987. Effect of timber harvesting on extractable nutrients in a northern Rocky Mountain forest soil. Canadian Journal of Forest Research. 17: 735-739.

Feller, M.C. 1988. Relationships between fuel properties and slashburning-induced nutrient losses. Forest Science. 34: 998-1015.

Ferguson, I.S.; McKimm, R.J. 1975. Establishment techniques at Koetong plantation, Victoria: a multivariate analysis and comparison. Australian Forestry. 30: 34-43.

Flinn, D.W. 1978. Comparison of establishment methods for *Pinus radiata* on a former *P. pinaster* site. Australian Forestry. 41: 167-176.

Flinn, D.W.; Hopmans, P.; Farrell, P.W.; James, J.M. 1979. Nutrient loss from the burning of *Pinus radiata* logging residue. Australian Forest Research. 9: 17-23.

Fowler, W.; Hevey, J.D. 1981. Soil and air temperature and biomass after residue treatment. Res. Note PNW-383. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 8 p.

Fowler, W.B.; Lopushinsky, W. 1989. An economical, digital meter for gypsum soil moisture blocks. Soil Science Society of America Journal. 53: 302-305.

Hart, G.E.; DeByle, N.V.; Hennes, R.W. 1981. Slash treatment after clearcutting lodgepole pine affects nutrients in soil water. Journal of Forestry. 79: 446-449.

Herring, H.G. 1968. Soil-moisture depletion by a central Washington lodgepole pine stand. Northwest Science. 42: 1-4.

Herring, H.G. 1970. Soil moisture trends under three different cover conditions. Res. Note PNW-114. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 8 p.

Hungerford, R.D. 1980. Microenvironmental response to harvesting and residue management. In: Environmental consequences of timber harvesting in Rocky Mountain coniferous forests: Proceedings of a symposium; 1979; Missoula, MT. Gen. Tech. Rep. INT-90. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 37-73.

Hungerford, R.D.; Babbitt, R.E. 1987. Overstory removal and residue treatments affect soil surface, air, and soil temperature: temperature implications for seedling survival. Res. Pap. INT-377. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 19 p.

Keeney, D.R.; Nelson, D.W. 1982. Nitrogen-inorganic forms. In: Methods of soil analysis, part 2. Page, A.L.; Miller, R.H.; Keeney, D.R., eds. Madison, WI: American Society of Agronomy: 643-698.

Keeves, A. 1966. Some evidence of loss of productivity with successive rotations of *Pinus radiata* in the south-east of South Australia. Australian Forestry. 30: 51-63.

Klock, G.O.; Grier, C.C. 1979. Effects of fire on the long-term maintenance of forest productivity. In: Forest fertilization conference: Proceedings of a symposium; 1979 September 25-27; Union, WA. Contribution 40. [Place of publication unknown]: University of Washington, College of Forest Resources, Institute of Forest Resources: 247-250.

Klock, G.O.; Lopushinsky, W. 1980. Soil water trends after clearcutting in the Blue Mountains of Oregon. Res. Note PNW-361. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 8 p.

Kimmins, J.P.; Feller, M.C. 1976. Effect of clearcutting and broadcast slash burning on nutrient budgets, streamwater chemistry and productivity in western Canada. In: Proceedings of the 16th International Union of Forest Research Organizations, World Congress, division 1; 1976 September; Oslo, Norway. Oslo, Norway: Norwegian International Union of Forest Research Organizations Norwegian Congress: 186-197.

Kraemer, J.F.; Hermann, R.K. 1979. Broadcast burning: 25-year effects on forest residues in the western flanks of the Cascade mountains. Forest Science. 25: 427-439.

Landis, T.D. 1985. Mineral nutrition as an index of seedling quality. In: Duryea, M.L., ed. Evaluating seedling quality: principles, procedures, and predictive abilities of major tests. Corvallis, OR: Oregon State University Press: 29-48.

Little, S.N.; Klock, G.O. 1985. The influence of residue removal and prescribed fire on distributions of forest nutrients. Res. Pap. PNW-338. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 12 p.

Little, S.N.; Ohmann, J.L. 1988. Estimating nitrogen lost from forest floor during prescribed fires in Douglas-fir/western hemlock clearcuts. Forest Science. 34: 152-164.

Lopushinsky, W.; Kaufmann, M.R. 1984. Effects of cold soil on water relations and spring growth of Douglas-fir seedlings. Forest Science. 30: 628-634.

Lopushinsky, W.; Max, T.A. 1990. Effect of soil temperature on root and shoot growth and on budburst timing in conifer seedling transplants. New Forests. 4: 107-124.

Lotan, J.E.; Perry, D.A. 1976. Effects of residue utilization on regeneration of lodgepole pine clearcuts. In: Proceedings of the symposium on terrestrial and aquatic ecological studies of the Northwest; 1976 March 26-27; [Meeting location unknown]. Cheney, WA: Eastern Washington State College Press: 125-133.

Maguire, C.C. 1983. First year response of small mammals to clearcuts in the Klamath Mountains of northern California. New Brunswick, NJ: Rutgers University. 233 p. Ph.D. thesis.

Minore, D. 1986. Effects of site preparation on seedling growth: a preliminary comparison of broadcast burning and pile burning. Res. Note PNW-RN-452. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 11 p.

Nelson, D.W.; Sommers, L.E. 1982. Total carbon, organic carbon, and organic matter. In: Page, A.L.; Miller, R.H.; Keeney, D.R., eds. Methods of soil analysis, part 2. Madison, WI: American Society of Agronomy: 539-580.

Olsen, S.R.; Sommers, L.E. 1982. Phosphorus. In: Page, A.L.; Miller, R.H.; Keeney, D.R., eds. Methods of soil analysis, part 2. Madison, WI: American Society of Agronomy: 403-430.

Pritchett, W.L.; Fisher, R.F. 1987. Properties and management of forest soils. New York: John Wiley and Sons. 435 p.

Ream, C.H.; Gruell, G.E. 1980. Influences of harvesting and residue treatments on small mammals and implications for forest management. In: Environmental consequences of timber harvesting in Rocky Mountain forests: Res. Pap. INT-377. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 455-467.

Rhoades, J.D. 1982. Soluble salts. In: Page, A.L.; Miller, R.H.; Keeney, D.R., eds. Methods of soil analysis, part 2. Madison, WI: American Society of Agronomy: 167-180.

Rosen, K.; Lundmark-Thelin, A. 1987. Increased nitrogen leaching under piles of slash-harvesting techniques. Scandinavian Journal of Forest Research. 2: 21-29.

Sandberg, D.V.; Peterson, J.L.; Ottmar, R.D. [and others]. 1989. Effect of utilization practice trends on air pollution from slash burning. Final report. Portland, OR: U.S. Department of Energy, Pacific Northwest and Alaska Regional Bioenergy Program, Bonneville Power Administration. 75 p.

Schmidt, W.C. 1982. Regeneration and growth of conifers. In: Benson, R.E., ed. Management consequences of alternative harvesting and residue treatment practices-lodgepole pine. Gen. Tech. Rep. INT-132. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 18-23.

Schmidt, W.C.; Lotan, J.E. 1980. Establishment and initial development of lodgepole pine in response to residue management. In: Environmental consequences of timber harvesting in Rocky Mountain forests. Res. Pap. INT-377. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 271-286.

Shearer, R. 1980. Regeneration establishment in response to harvesting and residue management in a western larch/Douglas-fir forest. In: Environmental consequences of timber harvesting in Rocky Mountain forests. Res. Pap. INT-377. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 249-269.

Squire, R.O.; Farrell, P.W.; Flinn, D.W.; Aeberli, B.C. 1985. Productivity of first and second rotation stands of *radiata pine* on sandy soils. II: Height and volume growth at five years. Australian Forestry. 48: 127-137.

Squire, R.O.; Flinn, D.W.; Farrel, P.W. 1979. Productivity of first and second rotation stands of *radiata pine* on sandy soils. I: Site factors affecting early growth. Australian Forestry. 42: 226-235.

Tevis, L. 1956. Response of small mammal populations to logging Douglas-fir. Journal of Mammology. 37: 189-196.

Tiedemann, A.R.; Anderson, T.D. 1971. Rapid analysis of total sulphur in soils and plant material. Plant and Soil. 35: 197-200.

Vihnanek, R.E.; Ballard, T.M. 1988. Slashburning effects on stocking, growth, and nutrition of young Douglas-fir plantations in salal-dominated ecosystems of eastern Vancouver Island. Canadian Journal of Forest Research. 18: 718-722.

Youngberg, C.T. 1984. Soil and tissue analysis: tools for maintaining soil fertility. In: Duryea, M.L.; Landis, T.D., eds. Forest nursery manual: production of bareroot seedlings. Boston: Martinus Nijhoff/D.W. Junk: 75-80.

☆U.S. GOVERNMENT PRINTING OFFICE: 1992 - 691-000/60045

Lopushinsky, W.; Zabowski, D.; Anderson, T.D. 1992. Early survival and height growth of Douglas-fir and lodgepole pine seedlings and variations in site factors following treatment of logging residues. Res. Pap. PNW-RP-451. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 22 p.

Logging residues were (1) broadcast burned, (2) piled and burned, (3) removed, or (4) left in place after clearcutting in a high-elevation subalpine fir/lodgepole pine forest in north-central Washington. Survival, height growth, and nutrient content of foliage of planted Douglas-fir and lodgepole pine seedlings, and variation in soil factors (nutrients, temperature, moisture, and compaction) and air temperature were compared for the four treatments. Little height growth occurred the first year, and it was similar for all treatments, probably due to transplant shock. Height growth the second year increased the most in the burned treatments, and the least in the slash-left treatment. Levels of nutrients in foliage were similar for all treatments and above threshold-deficiency levels except for sulfur. Extractable soil nutrients increased with burn treatments but returned to levels in other treatments within 3 years. Best performance of seedlings during the first 2 years was in burn treatments.

Keywords: Douglas-fir, lodgepole pine, residue treatment, reforestation, soil nutrients, seedling microclimate.

Pacific Northwest Research Station
333 S.W. First Avenue
P.O. Box 3890
Portland, Oregon 97208-3890

NATIONAL FORESTS 1891-1991

U.S. Department of Agriculture
Pacific Northwest Research Station
333 S.W. First Avenue
P.O. Box 3890
Portland, Oregon 97208